A 20-YEAR INDUSTRY PLAN FOR WINDOW TECHNOLOGY

WINDOW INDUSTRY TECHNOLOGY ROADMAP

OFFICE OF BUILDING TECHNOLOGY, STATE AND COMMUNITY PROGRAMS
ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY
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ACKNOWLEDGEMENTS

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American Architectural Manufacturers' Association (AAMA)

AFG Industries

Alliance to Save Energy

Andersen Corporation

Anstead Design Group

Apogee/Wausau Metals

Aspen Research

Cardinal IG

Certainteed

Donnelly Corporation

Efficient Windows Collaborative

Gilkey Window Company

Graham Architectural Products

Guardian Industries Corp.

The Home Depot

Jeld-Wen

Kawneer Co.

Libbey-Owens-Ford Co.

Marvin

Mikron Industries

NAHB Research Center

National Fenestration Rating Council (NFRC)

Pella Corporation

Plate Glass Manufacturers Council (PGMC)

PPG Industries

Velux

Viracon

Window and Door Manufacturers Association (WDMA)

A Window to the Future

The American window industry has taken an important first step in defining its future in response to changing market and business conditions. The industry faces exciting new opportunities but also serious challenges. New technology is expected to play a pivotal role in addressing these conditions, as well as assisting window manufacturers in competing in the marketplace. The pace of technological development should continue to respond to trends in new construction and retrofit that place a premium on energy conservation, enhanced quality, fast delivery, and low installed cost.

The *Window Industry Technology Roadmap* represents the collaborative efforts of window industry professionals, government, environmental organizations, and research groups. These individuals contributed to a dynamic process that ultimately produced general consensus on a vision for the future and the pathways for achieving it.

A NEW INITIATIVE

The U.S. Department of Energy's Office of Building Technology, State and Community Programs (BTS) is facilitating a new industry-led initiative to develop a series of technology roadmaps. The roadmaps identify key goals and strategies for different areas of the building and equipment industry. The *Window Industry Technology Roadmap* is one of the first sponsored by BTS.

This roadmapping initiative is a fundamental component of the BTS strategic plan and will help to align government resources with the high-priority needs identified by industry. The roadmap will guide cooperation among public and private researchers, window companies, and other State and Federal offices to help the window industry achieve its long-term vision.

EXECUTIVE SUMMARY

In September 1998, the window industry began the process of developing the *Technology Roadmap* with a one-day Executive Visioning Forum held in Chicago. During this forum, industry participants discussed their current situation and outlined a long-range vision for maintaining and building their competitive market position. This vision discussion led to the development of the vision statement below.

The core of the workshop explored the critical need to meet the vision in the areas of:

1. Windows as an integral part of a building "system"
2. Active, smart glass and windows
3. Informed consumers at all levels
4. More glass and windows used in buildings
5. Windows as an environmental solution
6. Windows as an energy source

Advanced window technology can lower production costs and create high-profit, innovative products to compete with other materials. Recognizing the importance of cooperative technology planning, the window industry organized a Window Technology Roadmap Workshop, held in January 1999 in Leesburg, Virginia. Over 30 representatives from the fenestration industry, government, environmental organizations, and research groups met to complete an industry-wide plan for achieving the industry vision. This collaborative workshop helped identify key targets of opportunity, technology barriers, and research priorities to meet the vision. These are summarized in the table on the next page.

BARRIERS TO THE VISION

At the Window Technology Roadmap Workshop, participants identified key market, policy, and technology barriers to achieving the window industry vision. Participants voted to select the most critical barriers in each category, and then developed specific strategies to overcome these barriers (see facing page).

Key market barriers:

- Lack of educated demand for innovative new window products
- High first cost of innovative new products

Key policy barrier:

- Dissimilar, poorly enforced, and inconsistent building codes

Key technology barriers:

- Lack of integration tools and forms needed to achieve true system integration
- Ambiguous definition of "durability" and its implications for warranty

VISION STATEMENT

In 2020, consumers recognize windows[1] as affordable "appliances in the wall" that are active and interactive parts of a true building system. Windows offer added value by providing energy, entertainment, and information with enhanced comfort, lighting, security, and aesthetics, in harmony with the natural environment.

[1] The term "window" in the vision statement, as well as in the document, refers to fenestration products, including windows, doors, and skylights.

SELECTED HIGH-PRIORITY ACTIONS FOR THE WINDOWS INDUSTRY

NEAR-TERM (0–3 YEARS)

Market Actions

- Establish partnerships through collaborative work among multiple stakeholders and resource groups.
- Conduct a value-based market analysis.
- Support, specify, and identify applications for improved technology, including breakthrough materials and manufacturing processes.
- Provide incentives such as financing programs and low interest loans, perhaps as an expanded ENERGY STAR component.

Policy Actions

- Combine the three existing codes by supporting the International Code Council (ICC), professional lobbying, or creating a core industry group.
- Educate local building inspectors.
- Develop communication channels among building industry groups to address integration issues in areas of education, research, and collaboration.

Technology Actions

- Define standards and protocols for integrating different building components.
- Develop strategies and hardware necessary to optimize integrated building systems.
- Define performance metrics for comfort, system integration, energy, cost, and environmental impacts.
- Develop methods for measuring the value of integrated systems.
- Establish a system for rating products on the basis of durability.
- Define appropriate durability and warranty periods for different window components.

MID-TERM (3–10 YEARS)

Policy Actions

- Establish a regionally sensitive national building code.

Technology Actions

- Develop analytical tools to assist manufacturers in designing and marketing efficient windows.
- Develop methods to measure and prove durability of fenestration products.
- Support, specify, and identify applications for improved technology, including breakthrough materials and manufacturing processes.
- Develop products that encourage consumers to upgrade as features advance (replaceable, portable, modular, high value).

LONG-TERM (10–20 YEARS)

Technology Actions

- Develop long-term photovoltaic products that can be integrated in fenestration products.
- Develop superior insulating materials and components for fenestration products.
- Develop integrated electronics in fenestration products.

CROSSCUTTING (ONGOING)

Market Actions

- Educate stakeholders and end users on true long-term cost benefits of high-performance products.

Technology Actions

- Develop products that encourage consumers to upgrade as features advance (replaceable, portable, modular, high value).
- Understand current technology and potential applications and specify technology needs as identified by user expectations.

Economic, Social, and Technology Trends Shape Industry Vision

INTRODUCTION

THE PROCESS

The *Window Industry Technology Roadmap* represents the collaborative efforts of fenestration experts from private companies as well as government, environmental, and research groups. Major steps in the development process included:

Executive Visioning Forum

When and where: September 1998 in Chicago, Illinois

Who participated: Two dozen window industry executives

Results included: Examination of the current environment and development of a shared industry vision

Roadmapping Workshop

When and where: January 1999 in Leesburg, Virginia

Who participated: More than 30 representatives from industry, government, environmental, and research groups

Results included: Identification of key barriers to achieving the vision and development of specific actions to overcome these barriers

Survey of Workshop Participants

A questionnaire distributed to workshop participants asked respondents to identify specific research needs and rate the investment required, potential contribution toward the vision, and the certainty of success for each. The *Technology Roadmap* represents the aggregation of those responses.

STATE OF THE WINDOW INDUSTRY

In addition to over 400 window fabricators, the window industry includes glass manufacturers, vinyl and aluminum extruders, wood suppliers, distributors, retailers, and contractors. Serving primarily residential and commercial markets, window sales exceeded 1,200 million square feet and $7 billion in 1997. Owing to their increasing versatility, windows make up a striking portion of wall area in new construction—13 percent in new residences to 50 percent in large office buildings. The window industry of today is a vibrant, modern set of businesses and is well positioned for the challenges it will face in the next two decades.

CONTEXT FOR THE VISION

In spite of the success of the window industry, significant challenges lie ahead. The industry must continue to meet society's changing expectations while remaining economically viable and globally competitive. Two dozen window industry members discussed their current situation and established their vision for the future during the Executive Forum held in Chicago in September 1998.

The window industry is in the midst of rapid technological change. Recent developments in glazing, framing, and assembly have dramatically improved the energy conservation potential and quality of new windows. This pace of technological development should continue in response to trends in new construction and retrofit that place **a premium on energy conservation, enhanced quality, fast delivery, and low installed cost.** Trends in the window industry, economy, and society will drive the window industry of the future, as will uncertainties and the rapid advance of technology.

CONTEXT FOR THE INDUSTRY VISION

INDUSTRY TRENDS

Industrial trends reflect vigorous competition in the construction products market:

- Shift toward low-e glazing and new framing materials
- Reduction in production cycle time
- Increased automation
- Development of systems approach to building design
- Declining window prices
- Consolidation of fabricators and contractors

ECONOMIC CLIMATE

Economic trends reveal opportunities for windows to provide additional value to consumers:

- Rise in disposable income
- Growth in replacement market through renovation and upgrading
- A strong economy
- Low energy prices

SOCIAL TRENDS

Social trends hint at changes in consumer perceptions and values:

- Aging population
- Increase in home ownership
- Heightened environmental awareness
- Increased role of women in purchases of home building products

POTENTIAL BARRIERS

Some important trends remain uncertain, and the industry's vision must be flexible and responsive to:

- Deregulation of utilities
- Housing and construction trends
- Enforcement and compliance of building codes

TECHNOLOGY FACTORS

The window industry is in the midst of the greatest technology change in its 300-year history—a phenomenon that influences industry dynamics into the foreseeable future:

- Opportunity for market differentiation
- Accelerating rate of technology change

REGULATORY TRENDS

Government programs and regulatory efforts have the potential to either enhance or stifle innovation:

- Growing industry participation in the regulatory process
- Growing appeal of ENERGY STAR labeling to consumers
- Reduction in capital gains tax

Vision and Barriers

Key Elements of the Vision

The vision statement is supported by six vision elements as articulated in the Executive Forum discussion. These are:

1. ***Windows as an integral part of the building system***
2. ***Active, smart glass and windows***
3. ***Informed consumers at all levels***
4. ***More glass and windows used in buildings***
5. ***Windows as an environmental solution***
6. ***Windows as an energy source***

Each of the BTS roadmaps begins with the definition of the industry's vision for itself in 2020. The 20-year horizon stimulates industry members to imagine their ideal world without concern for present-day barriers.

Executive Forum participants developed their vision of the future using graphical facilitation techniques. Facilitators asked two groups of participants to imagine future cover stories that heralded their success. They envisioned that, in the next 20 years, the U.S. window industry will offer its customers imaginative new products that challenge traditional perceptions. Windows will become **active, integral parts** of building climate, energy, information, and structural systems. **Responsible manufacturing practices, material selection, and energy efficiency characteristics** will combine to also make windows a solution to environmental concerns. To help customers understand the added value that windows offer them over competing building products, members of the window industry will become **premier educators.** All these efforts will **increase demand for windows as an alternative to competing building components and appliances,** thereby enhancing the industry's growth and contributing to its strength.

Industry members condensed their vision into the compelling vision statement below.

Vision Statement

In 2020, consumers recognize windows as affordable "appliances in the wall" that are active and interactive parts of a true building system. Windows offer added value by providing energy, entertainment, and information with enhanced comfort, lighting, security, and aesthetics, in harmony with the natural environment.

BARRIERS TO THE VISION

In order to achieve the vision, the window industry must overcome barriers. Industry members reconvened in Leesburg, Virginia, on January 5–6, 1999, to identify the key barriers in the areas of technology, market, and policy, and to outline strategies for overcoming them. Participants voted on which barriers to discuss further during the workshop, and specific actions were developed to address the most important barriers. This germinal roadmap emphasized industry's near-term priorities in each of the three areas: technology, market and policy.

TECHNOLOGY BARRIERS

✔	15	Lack of integration tools and forms to achieve true system integration
✔	14	Ambiguous definition of "durability" and its implications for warranty
	7	High cost of manufacturing, materials, and research
	2	Consumer and corporate mindset against the vision
	2	Absence of interconnection and control technologies for building systems
	1	Presence of competing technologies such as opaque walls and artificial lighting
	1	Long product development and cycle times

Note: Checkmarks indicate the barriers that were selected for further discussion in the workshop at Leesburg, Virginia. Numbers indicate the number of votes received.

Barrier: LACK OF INTEGRATION TOOLS AND FORMS

Actions:

- Define interface standards and protocols for integrating different building system components.
- Develop strategies and hardware necessary to optimize integrated building systems.
- Define performance metrics for comfort, system integration, energy, cost, and environmental impacts.
- Develop methods for measuring the value of integrated systems.

Barrier: DEFINITION OF DURABILITY AND IMPLICATIONS FOR WARRANTY

Actions:

- Establish a system for rating products on the basis of durability.
- Define appropriate durability and warranty periods for different window components.
- Develop products that encourage consumers to upgrade as features advance (replaceable, portable, modular, high value).

MARKET BARRIERS

✔ 19 Lack of educated demand

✔ 14 High first cost

4 Fragmentation in the fenestration and building industries

3 Lack of product differentiation by non-cost attributes

2 Resistance to partnering among industry members

Barrier: LACK OF EDUCATED DEMAND

Actions:

- Understand the market by clearly identifying the audience.
- Create and use tools.
- Understand current technology and potential applications and specify technology needs as identified by user expectations.
- Establish partnerships through collaborative work between multiple stakeholders and resource groups.

Barrier: HIGH FIRST COST

Actions:

- Educate stakeholders and end users on true long-term cost benefits.
- Conduct a value-based market analysis.
- Support, specify, and identify applications for improved technology, including breakthrough materials and manufacturing processes.
- Provide incentives such as financing programs and low interest loans, perhaps as an expanded ENERGY STAR component.

POLICY BARRIERS

✔ 19 Dissimilar, poorly enforced, and inconsistent building codes that contradict DOE and industry goals

9 No teeth in code enforcement

6 Undermining of local code enforcement by special interest groups

4 Limited Congressional support for end-use versus supply-side programs

1 Lack of compelling national energy policy

1 Lack of Congressional support for integrated roadmaps

1 Lack of clarity about how to measure success

Barrier: DISSIMILAR, POORLY ENFORCED, AND INCONSISTENT BUILDING CODES

Actions:

- Combine the three existing codes by supporting the ICC, professional lobbying, or creating a core industry group.
- Develop recommendation for Congressional legislation on establishing a regionally sensitive national building code.
- Develop communication channels among building industry groups to address integration issues in areas of education, research, and collaboration.

RESEARCH ACTIVITIES

MAPPING RESEARCH NEEDS AND STRATEGIES

The two workshops stimulated creative thinking and developed general consensus about the future of the window industry. They also identified interesting market transformation activities needed to support the vision. However, the workshops did not identify research needs and strategies in enough detail to complete the technology roadmap. Time constraints were partially the cause, and participants hesitated to discuss detailed research ideas in front of their competitors, even if the ideas were precompetitive.

To collect the necessary technical information free of the limitations imposed by the workshop environment, DOE distributed a questionnaire to over 20 workshop participants and researchers.

The surveys asked respondents to identify and describe specific research needs in the vision's five technical elements:

- Building integration—structural, power, and data interconnection between the window and the rest of the building
- Information display—passive, active, or interactive display of text or images
- Energy supply and conservation—annual or, ideally, instantaneous net provider of energy to the building
- Environmental harmony—minimal negative environmental impacts over the product life cycle
- Enhanced traditional features—improved window characteristics

For each research need, respondents also rated the investment required, the potential contribution toward each element of the vision, and the certainty of success. The respondents were contacted by phone to clarify and further develop their responses. The following technology roadmap represents the aggregation of those responses.

TECHNICAL ELEMENTS OF THE VISION

1. ***Building integration***
   Structural, power, and data interconnection between the window and the rest of the building
2. ***Information display***
   Passive, active, or interactive display of text or images
3. ***Energy supply and conservation***
   Annual or, ideally, instantaneous net provider of energy to the building
4. ***Environmental harmony***
   Minimal negative environmental impacts over the product life cycle
5. ***Enhanced traditional features***
   Improved window characteristics

Respondents identified 65 unique research activities that could move the industry toward its vision by overcoming technical barriers. In alphabetical order, they are:

ADVANCED HOLOGRAMS
Produce holographic images on windows

AEROGELS
Incorporate non-opaque, highly insulating aerogel into insulating glass units

ALTERNATIVE GLAZING MATERIALS
Develop more durable and efficient glazing materials

ALTITUDE ADAPTIVE IG
Redesign IG units to eliminate breakage due to bulging at high altitude

BILLET STOCK FROM RECYCLE
Develop suitable process for making billet out of recycled aluminum

BLAST-RESISTANT WINDOWS
Develop new, cost-effective, architecturally acceptable blast-resistant window materials

BUILDING ENERGY SOFTWARE
Develop software to predict the energy performance of a building

BUILDING INTEGRATION DEMONSTRATION
Demonstrate an integrated building system with windows

COATING EQUIPMENT
Design coating equipment flexible enough to apply a variety of coatings

COLOR PHOTOCHROMICS
Expand the color availability of photochromic materials

DAYLIGHTING RATING
Provide a rating to measure the amount of daylighting provided by a window

ELECTROCHROMIC DISPLAY
Develop "smart" windows

ELECTROCHROMIC FAILURE MODES
Identify electrochromic failure modes

ELECTROCHROMIC SCALE-UP
Prove electrochromics in commercial window sizes

ELECTROCHROMIC SERVICE-LIFE PREDICTION
Develop models to predict service life of electrochromics based on product specs and tests

ENERGY-EFFICIENT EXTRUSION
Reduce energy intensity of aluminum extrusion

ENVIRONMENTALLY BENIGN PHOTOVOLTAICS
Research and utilize environmentally benign photovoltaic (PV) materials

EXTERIOR DISPLAY
Display images on window exteriors

FENESTRATION DURABILITY
Research materials and finishes to extend efficient fenestration life

FIRE-RATED WINDOWS
Develop lower-cost alternative materials for fire-rated windows

GAS RETENTION
Test and predict gas concentration in IG units

GLASS/FRAME RATIO
Increase vision area without a corresponding increase in framing

HIGH-SECURITY WINDOWS
Develop new, stronger, cost-effective, architecturally compatible materials for high security

HOLOGRAMS
Exploit holography to direct exterior lighting within the interior space

HOLOGRAPHIC MODELING
Improve the modeling of the transmission of sunlight through holograms

IDENTIFY MARKETS FOR PROCESS WASTE
Find partners to use waste streams from window manufacturing operations

INSULATING COATINGS
Develop new colored architectural coatings that reduce conductive heat loss through window frames and sashes

INSULATING COMPONENTS
Develop new alloys or composites that reduce conductive heat loss through window components

INTEGRAL SMART SYSTEMS
Develop self-contained power supplies, sensors, controllers, and actuators to actively control heat and light transmission through the window

INTEGRAL WIND POWER RECOVERY
Integrate components into windows to capture wind energy

INTEGRAL WIRING
Incorporate wiring or wiring runs into the window

INTEGRATED BUILDING ENERGY SYSTEM SOFTWARE
Develop low-cost, user-friendly software to assess the energy savings inherent in integrated building systems

INTERIOR DISPLAY
Display images on window interiors

INTERIOR LIGHTING SOURCE
Transmit light from spandrel through ceiling space

INTERIOR PASSIVE LIGHTING
Develop light shelves for curtain wall and window wall applications

LARGER PV PANELS
Produce photovoltaic panels in sizes larger than 2'x4'

LASER IMPRINTING
Improve laser imprinting process for holograms on a commercial scale

LOW-COST IG
Develop new ways to produce affordable IG units

LOW-E COATINGS
Develop new generation of scratch-resistant, cleanable coating materials

MODULAR WINDOWS
Design new window system with permanent frames and modular windows

MONOCHROMIC ELECTROCHROMIC DISPLAY
Electrochromic display

MONOLITHIC TRANSPARENT INSULATING MATERIALS
Develop new non-glass insulating materials

MULTICHROMIC ELECTROCHROMIC DISPLAY
Electrochromic color display

PHOTOCHROMIC SCALE-UP
Prove photochromics in commercial window sizes

POWER SUPPLY MINIATURIZATION
Develop miniature, self-contained power supplies for active windows

POWER SYSTEM BALANCING
Develop power balancing/conditioning components that are integral to the window

PROJECTED DISPLAY
Project images onto windows similar to a “heads up” display

PROTOCOL FOR COMMUNICATION
Develop a means to communicate between various electronic components

PV COATINGS
Develop photovoltaic coatings

PV PANEL COLORS
Expand the color availability of photovoltaic panels

PV THIN FILM
Incorporate thin-film photovoltaics into fenestration products

PV VISION GLASS
Develop semitransparent photovoltaic glazing

RECYCLABILITY
Improve ability to disassemble dissimilar window materials for recycling

SLOPE U-FACTOR
Develop a U-factor rating suited to sloped skylights

SMART PHOTOCHROMICS
Develop photochromic glazings that also regulate heat transmission

SOFTWARE TOOLS TO QUANTIFY PERFORMANCE
Provide a simpler means to quantify performance through use of software

SOLAR HEAT GAIN
Develop a solar heat gain rating suited to skylights

STRONGER SEALANT
Strengthen the sealant bond in structural windows

SUNSCREENING
Develop skylight accessories to control conductive and radiant heat transmission

THERMAL MODELING SOFTWARE
Continue to improve the usability, flexibility, and cost of 3-D thermal models of window systems

THERMOCHROMICS SCALE-UP
Prove thermochromics in a commercial size window

UV RESEARCH BY MEDICAL RESEARCHERS
Research to understand the effects of ultraviolet light on humans

VACUUM GLASS
Develop commercially viable vacuum glass

VENTILATION
Develop fenestration systems that regulate or condition outdoor air for indoor use

WINDOW SELECTION SOFTWARE
Develop software to select windows based on impacts on building energy consumption

The research needs span many fields of research and segments of the window industry. All contribute positively to at least one of the vision’s technical elements.

RISK–CONTRIBUTION CHARTS

The Risk–Contribution charts on the following pages will help industry identify candidate research areas based on their risk tolerances and contribution to meeting the vision. Each chart represents a different technical element of the vision. Rather than financial return, "contribution" qualitatively measures each activity's potential to move the industry toward the vision element. Again, this may or may not equate to potential financial return.

Those interested in pursuing or funding research activities should know how each activity contributes to the overall vision and how much risk the activity entails. Risk applies to both the level of investment and the chances of success. Low investment levels and high likelihood of success equal low risk. Conversely, high investment levels and low likelihood of success equal high risk.

A higher level of risk usually demands a higher financial return. While the vision does not seek to quantify financial benefits, the industry expects that achieving it will mean higher sales and value-added. Thus, a research activity that makes a large contribution to the vision may also produce a large financial return. Companies typically make research decisions based on this balance of risk and potential return. However, in the case of an industry-wide vision, returns may accrue to companies other than those making the investment decision. Different aspects of the vision also may have different associated financial values. For these reasons, organizations that use the roadmap to guide their research should be careful to consider the benefits they can hope to capture.

Besides the differences organizations face in appropriating the returns from research efforts, organizations differ in their capacity and desire to bear risk. Conservative companies or organizations with smaller research budgets may be able to pursue only low-risk activities that offer the highest potential contribution to the vision. They may be able to fund higher-risk activities only through research collaboration and partnerships.

In general, organizations can pursue low-risk activities in the near term since investment levels are lower and there are fewer uncertainties to resolve. High-risk activities, although they may be coupled with higher potential payoffs, are generally appropriate for longer-term study, since there may be higher levels of spending required and more unknowns to explore. In this respect, the Risk–Contribution charts can also serve as a guide to near- and long-term priorities.

DETERMINING RISK

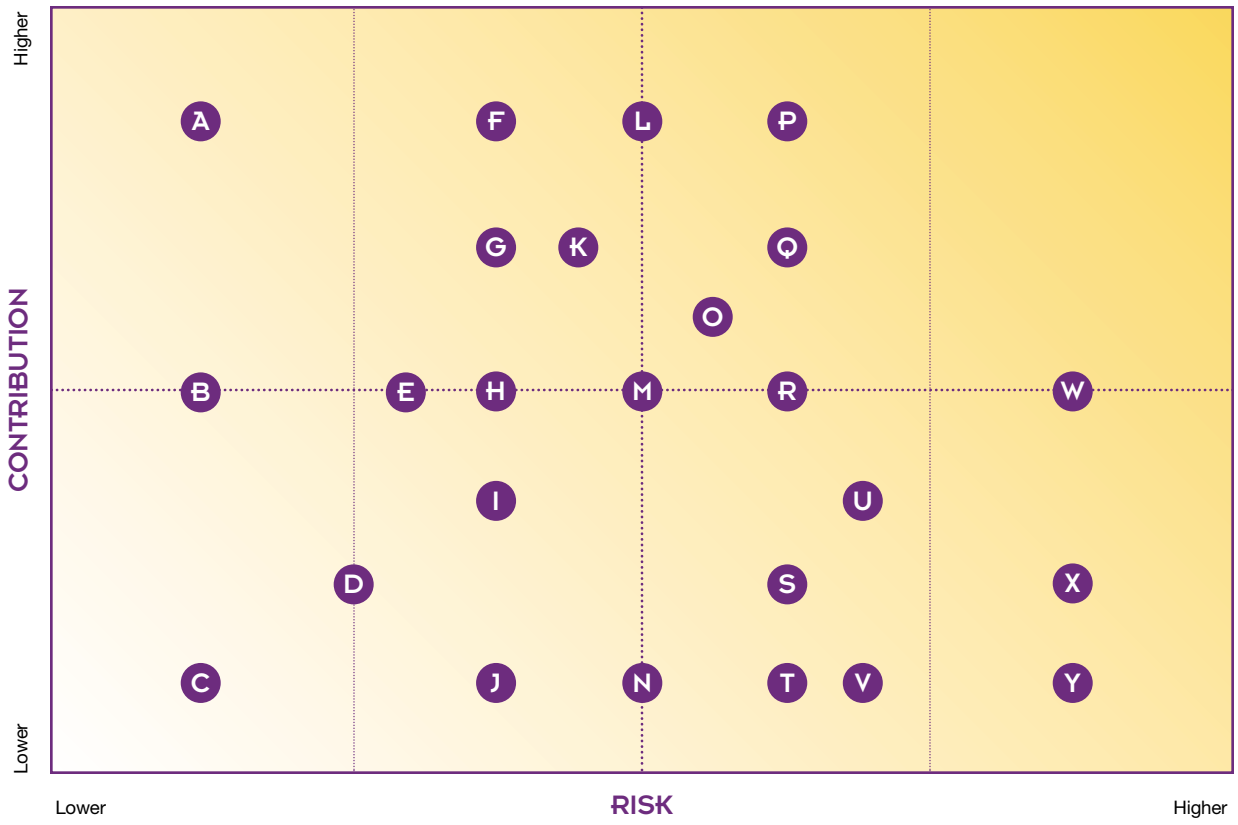
Investment Level—Respondents assigned a required investment level in relation to their own research budget:

Low	Could be funded within own research budget
Medium	May require some co-funding
High	Will require significant co-funding

Uncertainty Level—Respondents also ranked uncertainty on a low–medium–high scale.

Scoring—For both investment level and uncertainty level, low was assigned 1 point; medium, 2 points; and high, 3 points. Risk is merely the average of the two rankings, thereby putting it on the same 1 through 3 scale.

1. BUILDING INTEGRATION RESEARCH ACTIVITIES



A Modular windows

B Daylighting ratings
Life-cycle software/analysis

C Exterior display
Software tools to quantify performance

D Integral wind power

E Laser imprinting

F Building integration demo
Slope U-factor
Solar heat gain
Sunscreening

G Building energy software
Identify markets for process waste
Integral smart systems
Integral wiring
Interior lighting source
Larger PV panels
PV coatings
PV vision glass

H EC service-life prediction
Holographic modeling
Insulating coatings
Multichromic EC display

I Coating equipment

J Altitude adaptive IG
Interior display
Low-cost IG
Low-e coatings
Monochromic EC display
Monolithic transparent insulating materials
UV research by medical researchers

K PV panel colors

L Blast-resistant windows

M Alternative glazing materials
Power supply miniaturization

N Color photochromics
Glass/frame ratio
Insulating components
Smart photochromics

O Window selection software

P Protocols for smart system communication

Q Interior passive lighting
Power system balancing

R EC failure modes
Electrochromics scale-up
Environmentally benign PV
High-security windows
Holograms

S Billet stock from recycle
Photochromics scale-up
Projected display
Recyclability
Stronger sealant

T Aerogels
Energy-efficient extrusion
Fire-rated windows
Thermochromics scale-up

U PV thin film

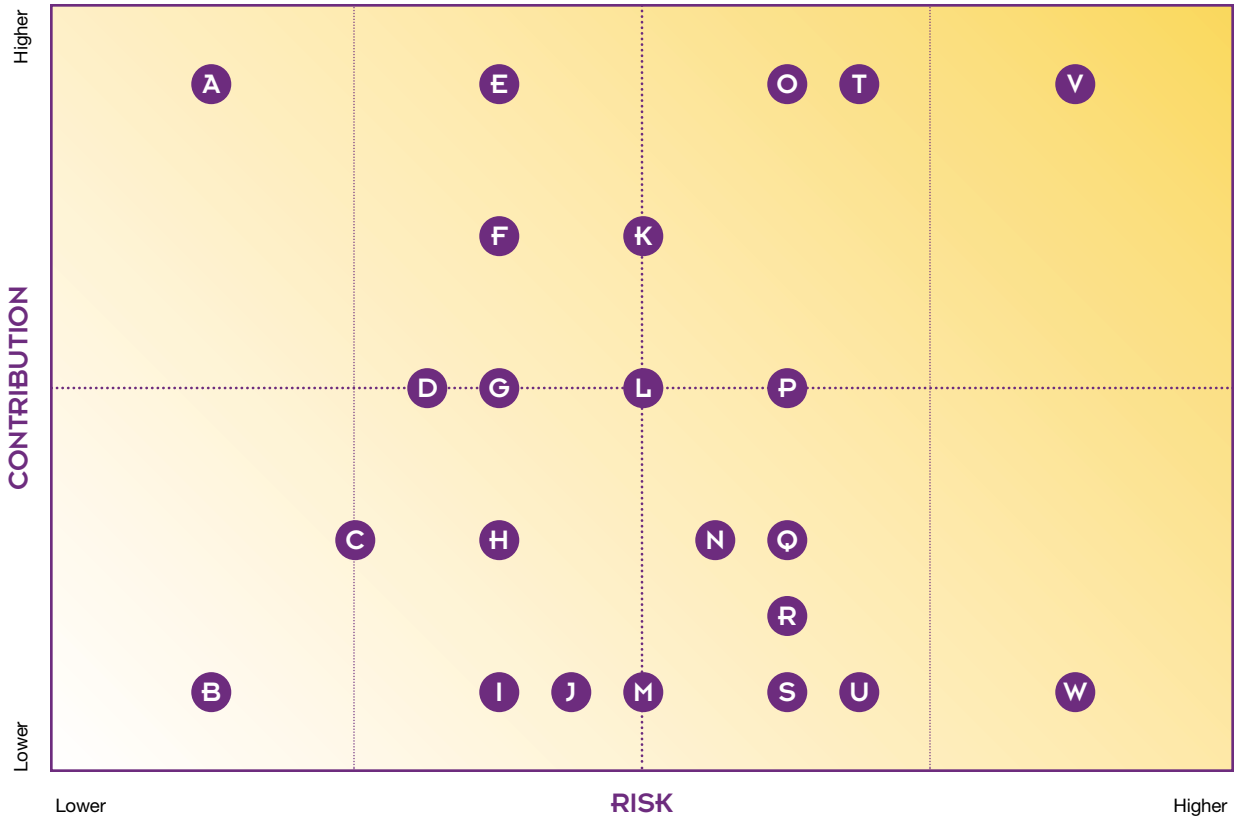
V Advanced holograms

W Fenestration durability

X Electrochromic display
Gas retention

Y Thermal modeling
Vacuum glass
Ventilation

2. INFORMATION DISPLAY RESEARCH ACTIVITIES



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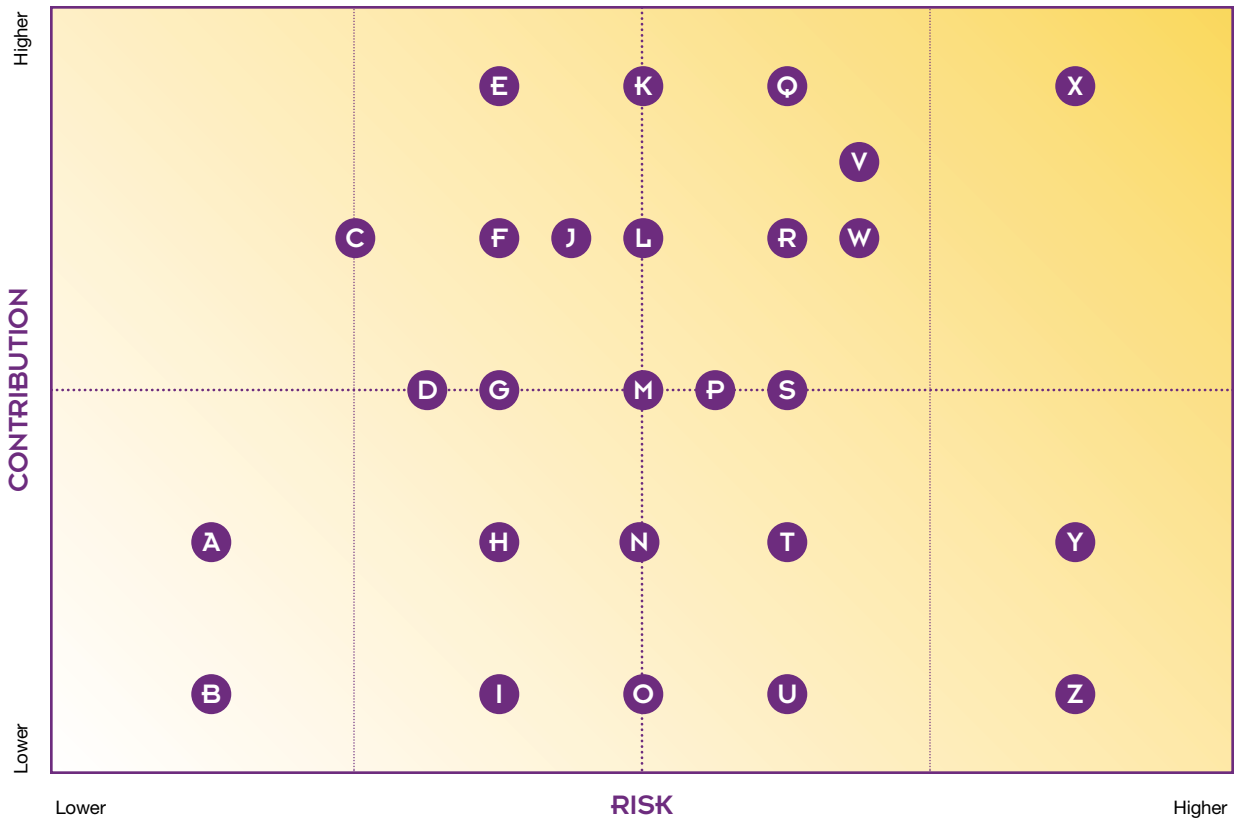
3. ENERGY SUPPLY AND CONSERVATION RESEARCH ACTIVITIES



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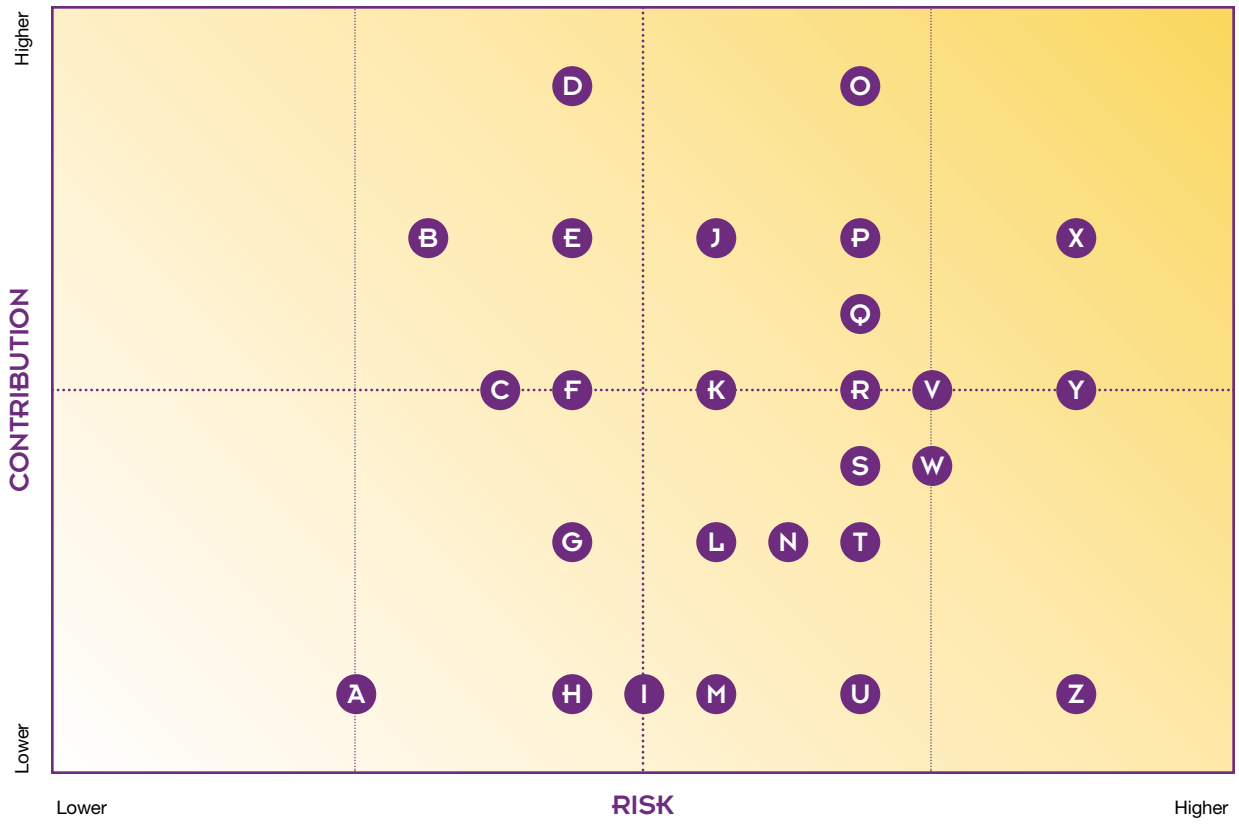
Vacuum glass

Y Electrochromic display
Ventilation

Z Fenestration durability

4. ENVIRONMENTAL HARMONY RESEARCH ACTIVITIES



A Daylighting ratings
Exterior display
Life-cycle software/analysis
Modular windows
Software tools to quantify performance

B Integral wind power

C Laser imprinting

D Slope U-factor
Solar heat gain
Sunscreening

E Identify markets for process waste
Larger PV panels
Low-e coatings

F Building integration demo
EC service-life prediction
Holographic modeling
Insulating coatings
PV coatings

G Coating equipment
Multichromic EC display

H Altitude adaptive IG
Building energy software
Integral smart systems
Integral wiring
Interior display
Interior lighting source
Low-cost IG
Monochromic EC display
Monolithic transparent insulating materials
PV vision glass
UV research by medical researchers

I PV panel colors

J Alternative glazing materials

K Insulating components

L Blast-resistant windows

M Color photochromics
Glass/frame ratio
Power supply miniaturization
Smart photochromics

N Window selection software

O Environmentally benign PV

P Billet stock from recycle
Energy-efficient extrusion
Recyclability

Q Aerogels

R EC failure modes
High-security windows
Photochromics scale-up
Thermochromics scale-up

S Electrochromics scale-up

T Holograms
Power system balancing
Projected display
Stronger sealant

U Fire-rated windows
Interior passive lighting
Protocols for smart system communication

V Advanced holograms

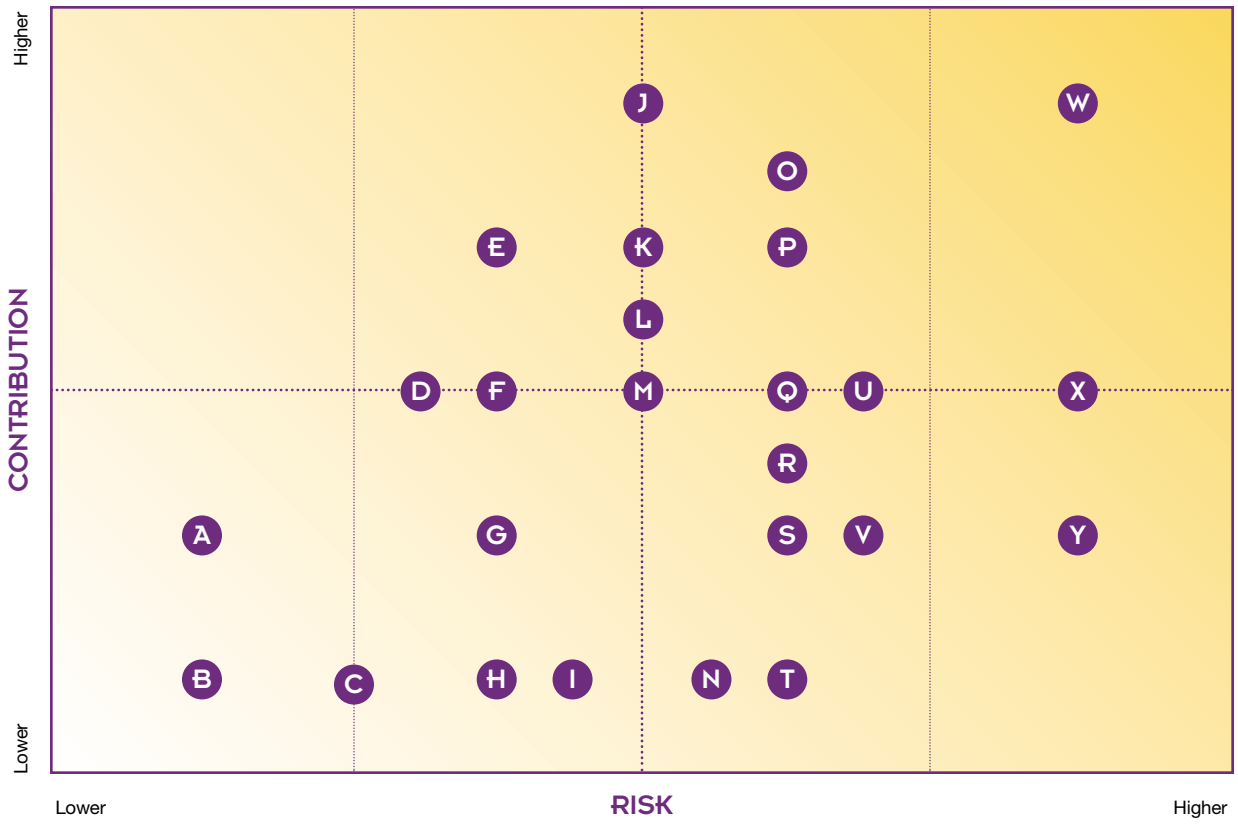
W PV thin film

X Fenestration durability
Ventilation

Y Electrochromic display
Vacuum glass

Z Gas retention
Thermal modeling

5. ENHANCED TRADITIONAL FEATURES RESEARCH ACTIVITIES



A Modular windows

B Daylighting ratings
Exterior display
Life-cycle software/analysis
Software tools to quantify performance

C Integral wind power

D Laser imprinting

E Building energy software
Integral smart systems
Interior lighting source

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Ventilation

Y Fenestration durability
Gas retention
Vacuum glass

RESEARCH ACTIVITIES

PRIORITY RESEARCH AREAS

1. *Imaging*
2. *Energy production and supply*
3. *Light transmission*
4. *Insulation*
5. *Analytical tools*
6. *Manufacturing*
7. *Design*
8. *Electronics*

Just as organizations may want to emphasize particular vision elements, organizations may want to identify activities based on their area of research expertise or interest. The 60 research activities listed on pages 10–11 were grouped into the following eight research areas:

1. Imaging—display of images or text on the window surface
2. Energy production and supply—development of window-based photovoltaic materials
3. Light transmission—control of radiant light and heat transmission through windows
4. Insulation—control of heat conduction through windows
5. Analytical tools—modeling of window-related phenomena and development of software-based tools
6. Manufacturing—equipment and processes for producing windows and window-related components
7. Design—design of buildings and building systems including windows
8. Electronics—development of integral components for controlling and powering window features

Research areas clarify the extent to which types of research needs contribute to various vision elements. This clarification can help an organization fund or organize efforts in the research areas that best support those vision elements it finds most appealing. For example, DOE may decide to emphasize research in those areas that best contribute to the vision's energy element. For organizations that conduct research, research areas can help them decide how they might best contribute to the vision based on how well their competencies match each element.

The following is a map for each of the priority research areas by topic.

RESEARCH PRIORITIES

Research Area	Continuing Research	Future Research
Imaging	• Projected display • Interior display	• Electrochromic display • Advanced holograms • Exterior display • Monochromic display • Multichromic display
Energy Production and Supply	• Larger PV panels • PV vision glass • PV thin film	• Environmentally benign PV materials • PV coatings • PV panel colors • Integral wind power
Light Transmission	• Electrochromics scale-up • Photochromics scale-up • Thermochromics scale-up • Holograms • Low-e coatings • UV research by medical researchers • Interior lighting source	• Smart photochromics • Color photochromics • Daylighting rating
Insulation	• Insulating components • Aerogels • Monolithic transparent insulating materials • Vacuum glass • Gas retention	• Insulating coatings • Alternative glazing materials
Analytical Tools	• Thermal modeling • Building energy software • Solar heat gain • Slope U-factor • Holographic modeling • EC failure modes • Life-cycle software/analysis • Window selection software	• Tools to quantify performance • EC service-life prediction
Manufacturing	• Billet stock from recycle • Energy-efficient extrusion • Laser imprinting • Low cost of efficient IG	• Recyclability • Coating equipment • Markets for process waste
Design	• Altitude adaptive IG • Stronger sealant • High-security windows • Glass/frame ratio • Blast-resistant windows • Fenestration durability • Fire-rated windows • Sunscreening • Interior passive lighting • Building integration demonstration	• Modular windows • Ventilation
Electronics	• Power supply miniaturization • Integral wiring • Power system balancing	• Integral smart system • Protocol for communication

Next Steps

Although product development is essential to the long-term success of the industry, it is a primary basis for competition among companies and is best left to the individual efforts of company proprietary research and development programs. However, studies of the fundamental physical characteristics of windows and complementing technologies are needed. Individual company researchers and product developers should use the results of this fundamental research to advance proprietary product development and to promote competition.

Meeting Long-Term Research Objectives

Achieving the goals identified in this document will require collaboration with government and other industries to leverage research and development funds. Collaboration will be required for the following long-term research objectives:

- Develop long-term photovoltaic products that can be integrated in fenestration products.
- Develop superior insulating materials and components for fenestration products.
- Develop analytical tools to assist manufacturers in designing and marketing efficient windows.
- Develop methods to measure and prove durability of fenestration products.
- Develop integrated electronics in fenestration products.
- Support, specify, and identify applications for improved technology, including breakthrough materials and manufacturing processes.
- Develop products that encourage consumers to upgrade as features advance (replaceable, portable, modular, high value).

Addressing Market and Policy Barriers

Research and development alone will not lead to achieving the vision. Government and industry will need to continue working together to address the market and policy barriers facing the window industry. Objectives include:

- Define interface standards and protocols for integrating different building system components.
- Develop communication channels among building industry groups to address integration issues in areas of education, research, and collaboration.
- Develop strategies and hardware necessary to optimize integrated building systems.
- Define performance metrics for comfort, system integration, energy, cost, and environmental impacts.
- Develop methods for measuring the value of integrated systems.
- Establish a system for rating products on the basis of durability.
- Define appropriate durability and warranty periods for different window components.
- Understand current technology and potential applications and specify technology needs as identified by user expectations.
- Educate stakeholders and end users on true long-term cost benefits.
- Provide incentives such as financing programs and low-interest loans, perhaps as an expanded Energy Star component.

Next Steps

Several next steps are needed to implement the vision and roadmap and to pursue research opportunities. They include:

- Create an industry task group to address appropriate industry and government roles in implementing the roadmap.
- Establish ad hoc working groups to examine the eight research areas in more depth and develop detailed research plans for each area.
- Simultaneously, DOE will identify areas in the roadmap that coincide with beneficial public policy and align its Federal research agenda accordingly.
- Continue “course correction” meetings with industry to ensure that the roadmap is a living, evolving document.

For more information, contact:

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